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A Review on Climate Change, Sea Level Change and Paleoclimate History

[1]Siti Zulaiha Binti Zolkaply, [1]Lubna Alam, [2]Ahmad Abas Kutty, [3]Firoz Khan and [1]Mazlin Mokhtar
[1]Institute for Environment and Development (LESTARI),
[2]School of Environmental and Natural Resource Sciences,
[3]Research Centre for Tropical Climate Change System, National University of Malaysia, Bangi,
43600 Selangor, Malaysia

Abstract: A continuous development and increasing urbanization at the coastal zones have occurred with little regard to the consequences of rising sea levels associated to climate change. An improved understanding of climate change and sea level rise should be provided to reduce the uncertainties corresponding with sea level rise projections which contribute to local adaptation planning. This review has provided an overview of 20 years scientific investigation on sea level projections and information of paleoclimate history from the last era. The presence of uncertainties and bias in the previous study related to sea level projections need a lot of improvement in the future. This review ends with a recommendation to conduct a more precise analysis by applying similar guidelines for all analysis among all researchers across the globe as well as full attention on the chosen of assessment approaches, related method and selection of space, time and distributional scale for analysis.

Key words: Sea level rise, climate change, vulnerability, uncertainties, distributional scale, assessment approaches

INTRODUCTION

Sea-level change associated with climate change had received a great attention worldwide due to the fact that much of the world's population and infrastructure are located along coastlines (Holligan and Boois, 1993; Turner *et al*., 1996; Sachs *et al*., 2001). It was recorded that people who live within one metre of high tide level is more than 150 million while 250 million people live within 5 m of high tide (Anthoff *et al*., 2006; Rowley *et al*., 2007). Severe impact of sea level rise on the coast include an increase in erosion and sedimentation, destruction of the ecosystem of mangrove and other marine habitat and damage of infrastructure along coastal areas such as bridges, revetments, groins, breakwater and jetty (Field *et al*., 2012).

There are numerous scientific literature discussed about climate change and its impact on living organisms and environment. However, there is lack of contribution of publication on sea level rise. In addition, many publication focused on climate change and sea level change at a present day as well as sea level projection in the future but the information about paleoclimate history that contribute towards current climatic condition is not well understood. The most acute sea level rise impact is occurred through extreme events, a period of above average sea level (Church *et al*., 2010). It involves various cyclones and associated storm surges that threatened human, plant and animals (Church *et al*., 2010).

Earth's paleoclimate history contained many helpful information on climate sensitivity from both natural and human-made forcings. The investigation about paleoclimate arised in the early 19th century. The discoveries about glaciations and natural changes in Earth's past climate promote a deeper understanding about the earlier phenomenon that occur over ten to hundreds of millions of years ago. It involves the oscillations of climate and atmospheric composition on Earth. The knowledge about paleoclimate history of the Earth helps to understand the causes and implication of current climatic condition. For example, factors of occurrence of continuous global warming and dangerous level of sea level rise. The level of global warming can also be predicted based on supporting information from paleoclimate record.

This review aims to make a general revision on the available research related to climate change and sea level rise, to identify climate sensitivity and potential human-made climate effects based on paleoclimate information and to look up a comparison between climate change and sea level rise scenarios in Malaysia and other regions in the world.

Corresponding Author: Lubna Alam, Institute for Environment and Development (LESTARI), National University of Malaysia, Bangi, 43600 Selangor, Malaysia

SEA LEVEL PROJECTIONS; TWENTY YEARS OF SCIENTIFIC INVESTIGATION

The first assessment of climate change was carried out by the Intergovernmental Panel on Climate Change (IPCC) in 1990 followed by UN Conference on Environment and Development (Rio Summit) in 1992 who conducted the UN Framework Convention on Climate Change. In 1995, the IPCC Second Assessment Report (SAR) was established. Several years later, numerous cooperative studies and reports on climate change were undertaken to identify the factors, consequences and history of global climate patterns.

In 2001, the IPCC introduced the Third Assessment Report (TAR) containing information about global climate change and sea level rise projections for 2100 compared with 1990 levels. The outcomes of this report is divided into three categories: the average of the TAR Model projections for the full range of greenhouse gas scenarios (30-50 cm), the range of all model projections over all scenarios (20-70 cm) and the full range of projections covering uncertainty in estimates of contribution from land-based ice, particularly for a sea level rise (9-88 cm). The TAR projections of sea level rise for the 21st century are similar to the next IPCC assessment report, the '4th Assessment Report (AR4), mainly at the upper end of the projected range.

The 1st part of AR4 shows similar but slightly smaller than the equivalent range from the TAR. The second part of AR4 is unsuccessful due to an absent of adequate models for quantitative estimates. The model-based estimation by the IPCC recorded a sea-level projections of about 1.9 mm/year. Based on the report, IPCC (2007) predicted sea level rise by the end of this century of about 29 cm. IPCC (2007) also claimed that the global rise in sea levels since last glacial maximum is 120 m. However, the projections of sea level by the IPCC (2007) excluded the information from ice sheet dynamics an important part that is not well understood enough. In addition, the interpretation of the IPCC (2007) on the rate of sea level rise was rejected by Gehrels (2010) probably due to the differences in method of collecting data of sea level. There are some limitations on the physical climate models used by the IPCC. Thus, another alternative approaches for sea level rise estimation is used.

Different approach on sea level prediction has been made by Rahmstorf based on semi-empirical model. He indicated that there is a linear relation between the rate of global sea level and global mean surface temperature. This hypothesis was tested using past sea level and temperature data. For example, an adjusted 20th century data inferred a 21st sea level rise of about a meter due to a continuous escalation of green house gases emissions. A good approximation for temperature and sea level changes was built with a proportionality constant of 3.4 mm/year/°C. The IPCC used this outcomes for sea-level rise projection in 2100 of 0.5-1.4 m above the 1990 level. However, the Rahmstorf model shows limitations due to its inability to adequately reproduce observed (Holgate *et al*., 2007) and modelled sea level rise.

In 2008, a new approach based on kinematic constraints was utilized by Pfeffer *et al.* (2008). The sea level rise more than 2 m by 2100 was classified as unjustified. A more conceivable estimate was about 80 cm which is consistent with the upper end of the IPCC projections and the present rate of sea level rise. The information on ice-sheet contributions is needed to support this value. The analysis performed by the Gravity Recovery and Climate Experiment (GRACE) satellite mission using space-based gravity data collected from 2002-2009 indicate an accelerating contribution from both Greenland and Antarctica (Velicogna, 2009), supported the range discussed by Pfeffer *et al.* (2008).

A broader range of sea level rise projections based on semi-empirical approaches was applied by Horton *et al.* (2008) based on the latest generation of Coupled Global Climate Models (CGCMs) used for the IPCC AR4. His investigation is comparable with Rahmstorf's study with a great improvement of spatial resolution and simulation of climate conditions such as the El Nino Southern Oscillation (ENSO) in respect to that of the IPCC TAR (Honghton *et al*., 2001) model cycle. However, the outcome of sea level projection from Horton *et al.* (2008) is higher than the IPCC AR4 and the methodology used has some weaknesses such as all relevant processes were excluded from CGCM simulations, SRES emissions scenarios that effectively omit carbon-cycle feedbacks and invalid historical relationships between global temperature and sea level rise.

In 2009, a more advance study was conducted by Vermeer and Rahmstorf (2009). They extended Rahmstorf's finding by providing a rapid response term, projecting sea level rise by 2100 of 0.75-1.9 m covering the full range of IPCC climate context. Grinsted *et al.* (2010) and Alley *et al.* (2005) proposed new approaches of sea level projections. A 4-parameter linear response equation to temperature and sea level data for the past 2000 years was fit by Grinsted *et al.* (2010) with a projections of sea level rise of 0.9-1.3 m by 2100 for a middle IPCC scenarios. The result of their finding of sea level projections is greater than the IPCC (2007) estimates which is typically a factor 3-4. As a result, the potential magnitude of human-caused sea level change is altered. Another study was conducted by Alley *et al.* (2010) on projections of sea level rise by 2100. They identified several clustered around 1 m and one outlier at 5 m as linear in a graph.

PALEOCLIMATE AND MODERN CLIMATE CHANGE PHENOMENON

The changes of sea level occur continuously, since, the last era which is more than 35 million years ago, a period when the grounded ice sheets was absent on the Earth. The solar radiation that reaches the Earth's surface due to the movement of the Earth around the Sun had altered the global average temperature changes and the sea level changes. A high concentration of greenhouse gas in the atmosphere resulted in a warmer temperature of the earth and the sea level reached 70 m above present day values (Alley *et al.* 2010). The effects of greenhouse period or Paleocene-Eocene Thermal Maximum (PETM) which caused considerable increase of sea-surface temperatures and sea levels at lower latitude allowed many tropical plants and animals to grow effectively (Hallam, 1984 ; Stanley, 2001). For example, mangroves, palm trees and alligators. In addition, the emergence of many marine fishes was contributed by the formation of tropical shallow-water reef environment during the warmed period (Westneat and Alfaro, 2005; Fessler and Westneat, 2007; Sorenson *et al*., 2013).

The most significant interval in Earth history occurred during the transition from the Eocene to the Oligocene Epochs, since, the extinction of dinosours at 65 Ma. This major climatic changes took place at 33.5 Ma (Miller *et al*., 1987). The warm 'greenhouse' climate of early Eocene (54-46 Ma) changed into 'icehouse', a much cooler and temperate climate by the early Oligocene (33 Ma). A major continental cooling at Northern middle and high latitudes and the development of an Antarctic ice cap arised at approximately half of its present size during the Eocene-Oligocene transition (Miller *et al*., 1987; Zachos *et al*., 1994, 2001). These climatic stresses are reflected by the extinctions of plants and animals on land and in the oceans (Prothero, 1994). For example, Planktonic Foraminiferans (Keller, 1983), Benthic Foraminiferans (Gaskell, 1991; Thomas, 1992), Diatoms (Baldauf, 1992), Ostracodes (Benson, 1975), Molluscs (Hansen 1987, 1992), Echinoids (McKinney *et al*., 1992) and many surviving species of Calcareous Nannofossils (Aubry, 1992).

A historical period which is about 125000 years ago during the last interglacial represented mostly similar climatic conditions to those expected in the latter part of the 21st century. The information from some Paleodata (Rohling *et al*., 2008) indicate that rates of sea level rise reached 1.6±0.8 m/century and sea level 4-6 m above present-day values (Overpeck *et al*., 2006). The global average temperatures recorded values that are higher than today, about 3-5°C (Otto-Bliesner *et al*., 2 006). Until the Greenland and Antarctic Ice sheets collapsed, sea level remained at about 130 m below today's values. The sea level rose very rapidly between 20000 years ago to about 7000 years ago at average rates of 1 m/century for many milennia (Church *et al*., 2010).

About 21,000 years ago during last glacial maximum, both poles and almost all parts of the Northern continents were covered by expanding ice sheets. Severe icehouse condition during Pleistocene Epoch showed a remarkable impact towards the shore lines and coral reefs of the Indo-Malay Region (Chappell and Thom, 1977; Voris, 2000). During glacials and interglacials period, the sea level fluctuated worldwide through a range of 100-120 m (Siddall *et al*., 2003). The Pleistocene Glaciation exposed two large shelve areas known as Sunda and Sahul shelves which led to several vicariance events to occur among marine fishes (Bellwood and Wainwright, 2002). During this time much of the world's water was frozen in glaciers and South-East Asian Peninsulars and islands were positioned above sea level. The 5 main refugees were introduced in the Indo-Malay-Philippine Archipelago (IMPA) during ice ages which are South China Sea, Celebes Sea, Sulu Sea, Banda Sea and Andaman Sea Fig. 1. The formation of Sundaland became a barrier for dispersal of marine fishes and introduced a series of local marine extinctions (Voris, 2000).

The formation of ice sheets at the Northern European and American causes the sea level over the following hundred thousand years to decline to about 130 m below today's values (Church *et al*., 2010). The sea level rose rapidly at average rates of 1 m/century with peak rates during the deglaciation potentially exceeding several meters per century when the ice sheets collapsed from 20,000 to about 7000 years ago (Fairbanks, 1989; Lambeck *et al*., 2002; Alley *et al*., 2005). The sea level rose more slowly from 6000-2000 years ago which is about 2.5 m over 4000 years followed by a more slowly over the last 2000 years ago to the 18th century. Although, the data of global average sea level rise only recorded about 0.2 mm/year over this latter period due to a continuing slow dynamic response to changes in climate, since, the Last Glacial Maximum (LGM) but the value is consistent with the indication of very low rates of sea level change from paleodata (Church *et al*., 2010).

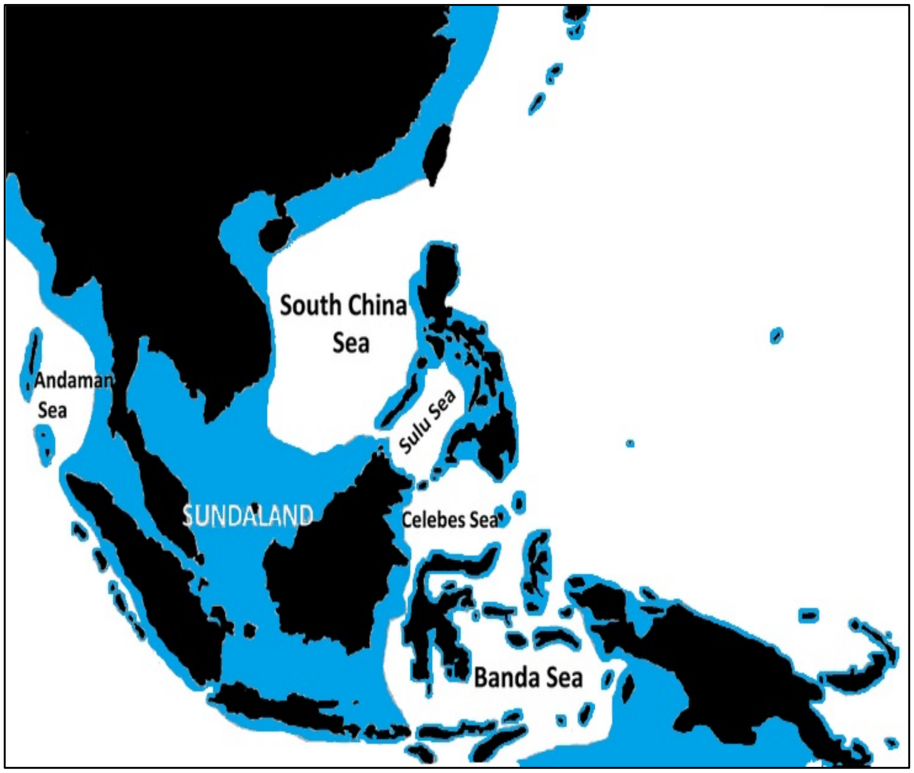

Fig. 1: Mop of IMPA

CLIMATE CHANGE AND SEA LEVEL RISE IMPACTS IN MALAYSIA AND OTHER COUNTRIES

A continuous variation in climate will affect all people around the world particularly the coastal wetland communities. The major effects of climate change mainly due to an extremely high temperature include sea-level rise, saline water intrusion into the bays and estuaries, ocean acidification and a more rapid spread of disease. The highest risk of human settlements and activities mainly for those concentrated near the coasts of both small islands and low-lying areas (McGranahan *et al*., 2007). This is because sea level rise is usually associated with extreme events such as storm surges or increase over the longer term (Bettencourt *et al*., 2006). The climate change and sea level rise phenomenon in each countries or regions varies considerably depending on its location on the globe. Among the most affected countries of the year 2004 based on the Climate Risk Index are Somalia, Dominican Republic, Bangladesh, Philippines, China, Nepal, Madagascar, Japan, USA, Bahamas and Germany (Anemuller *et al*., 2006).

The impacts of climate change and sea level rise in Malaysia is not as severe as other threatened countries that undergo the most serious disasters such as Tsunami, typhoon and landslides. However, coastal communities in Malaysia are vulnerable to flooding and damage in ecosystem as a result of the rising of sea level. Although, this phenomenon is dependent on monsoon condition, but it causes great impacts such as lost of place to live, destruction of natural habitat and spawning places for marine organisms, damaged the ecosystems for tourism and socioeconomic activities and damage the infrastructure and coastal development. The sustainability of island tourism in Malaysia is threatened by rising sea level which resulted in beach erosion and saline contamination of the coastal wells that are a main source of water supply for the resorts (Tan and Teh, 2001).

Among the largest population in Asia continent that has a significant exposure of sea level rise is Bangladesh. It is situated just above sea levels and is surrounded by deltaic areas of three large rivers namely Brahmaputra, Ganges and Meghna (Ericson *et al*., 2006). Bangladesh is usually affected by tropical cyclones and monsoon rainfalls. The problems arised when mangrove trees which provide natural coastal defences are destroyed by the expansion of aquaculture activities (Woodroffe *et al*., 2006). A continuous disastrous floods happens in Bangladesh in which more than half of the national territory was flooded and the most severe during heavy river floods in 1992 and 1998. The most dangerous phenomenon occurred during tropical cyclones in 1970 and 1991 in which some hundred thousand people were killed and houses, crops and hundreds of thousands livestock were swept away (Anemuller *et al*., 2006).

In the Philippines, a total of 11 events that threatened 1012 lives an caused economic losses in the amount of 120.95 million dollars were recorded in 2004. Beside that, the country are exposed to repeated series of droughts that are partially caused by El Nino and earthquakes (Anemuller *et al*., 2006). In different case, a 0.5 m rise in sea level combined with waves associated with a 1 in 50 year cyclone causes overtopping, damage to wharves and flooding of the hinterland of the port facilities at Suva, Fiji and Apia, Samoa (Hay *et al*., 2003).

Most of the world's megacities are located in vulnerable coastal regions. These cities are exposed to flooding from storm surges due to some of them are located on sinking deltaic regions. For example, New Orleans experienced Hurricane Katrina in 2005. In New York city, sea level rise increase vulnerability to flooding and storm surges. In addition, it is also affected by major hurricanes that travel Northward along a track slightly to its West in which the strongest winds would pass directly over the city (Gornitz *et al*., 2006).

The rate and magnitude of sea level rise can be overcome if global temperature and ocean thermal expansion are reduced by reducing the emission of greenhouse gases. The risk of sea level rise and extreme climate change demand various measures. Thus, the global population are responsible in the adaptation towards climate risks due to the local environmental, economic and social conditions are severely affected by extreme weather, climate change and sea level rise.

CONCLUSION

In this review, we compare the sea level projections based on different model approaches from year 1990- 2010. We also discover the history of climate change and sea level rise from the last era. These important information provide in-depth knowledge towards the causes and effects of the rising of sea levels associated to climate change. It was observed that some methods used for sea level projections still containing uncertainties due to the presence of bias in the assessment approaches, related method and our selection of space, time and distributional scales for analysis.

RECOMMENDATIONS

Thus, a more reliable analyses and similar guidelines to perform the analysis among all researches across the globe are critically warranted to avoid any errors and uncertainties in predicting climate and sea level change for future benefits.

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